Letters to the Editor: Comment and Reply

Comment

Predicted Environmental Impact and Expected Occurrence of Actual Environmental Impact
Part II: Spatial Differentiation in Life Cycle Assessment via the Site-Dependent Characterisation of Environmental Impact from Emissions by José Potting & Michael Hauschild, Int.J.LCA 2 (4) 209-216 (1997)

The Structure of Impact Assessment: Mutually Independent Dimensions as a Function of Modifiers

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POTTING & HAUSCHILD (1997, p. 210 *ff.*) propose to replace UDO DE HAES' (1996) four dimensions (effect, fate/exposure, background, spatial) by three (effect, fate, target). In this letter, we present a critique on their proposal, and at the same time try to disentangle the procedural framework in Life Cycle Impact Assessment.

We subscribe POTTING & HAUSCHILD's enthusiasm for UDO DE HAES clear distinction (p. 22) between dimensions of information and levels of sophistication (or closer to UDO DE HAES's original: more simple or more detailed information) within each dimension. We agree with POTTING & HAUSCHILD that the present dimensions are in some respects confusing, although we do not know if our arguments are the same as theirs, since they, unfortunately, do not mention them. It may be good to refer to UDO DE HAES' text at this point, in which a distinction is made between fate and effect as "dimensions which directly refer to the cause-effect chain" on the one hand and background and space as "additional conditions" on the other hand. This distinction is clearly illustrated in the same volume by JOLLIET (1996, p. 54), who describes space and background as “modifiers”. Despite this, they are still called dimensions, and to us this fact is the source of confusion.

POTTING & HAUSCHILD offer a proposal to overcome their confusion about the nature of the dimensions. The core of their proposal is to discard the third and fourth dimension (background and space) and introduce a new third one (target). While trying to resolve the existing problem, however, they introduce some new complications along with their solution. The most prominent one is the overlap between their effect dimension and their target dimension. For the content of the effect dimension, they refer to UDO DE HAES who writes on "standards, NOELs, NOAELs, or comparable types of data, […] the slope of the dose response curve" (p. 22). The newly introduced target information includes "concentration-effect curve, no-effect concentration, critical load, critical concentration" (fig. 2 on p. 211). It is interesting to observe that POTTING & HAUSCHILD refer to this figure when describing the fate factor (*F*) and the target factor (*T*), but not when describing the effect factor (*E*). The reason is obvious: the overlap between target factor and effect factor (both dealing with aspects like no-effect levels and dose-effect curves) makes it impossible to make a clear distinction between them.

We think that POTTING & HAUSCHILD rightly feel that the "modifiers" in the scheme of UDO DE HAES are not true dimensions, and also that some kind of "target information" needs to be covered by a separate dimension. In our view, however, such reconsideration needs a clear and sound basis, especially with respect to the nature of the concept dimension. Both UDO DE HAES and POTTING & HAUSCHILD rather seem to be driven by intuition, which makes them bring up valuable points, but fail in the elaboration by lack of consistency. Our aim is to pick up these points, and to order them in a consistent system, in which the modifiers of UDO DE HAES, the newly proposed target dimension and the "descriptors" of POTTING & HAUSCHILD will each play a role. The core of our proposal is to redefine the concept of dimension in a stricter sense, namely as mutually independent directions, and to interpret the modifiers/descriptors as parameters of which the dimensions are a function. Thus, from the very long heterogenous list of relevant aspects that comprises emitted amount, molecular weight, degradation times, partition coefficients, fate, concentration, exposure, intake, NOEC and effect, we single out four independent dimensions:

- emission
- fate
- intake*
- effect.

As we may assume that the emission dimension is dealt with in the inventory analysis, we thus deal with three dimension in characterization. A characterization formula will then assume the form

$$S_i^{nmj} = E_i^j \times I_i^{mj} \times F_i^{nm} \times M_i^n \quad (1)$$

* Note that we avoid the term exposure, and use the term intake instead, since exposure in some contexts refers to concentration, rather than intake, and may therefore be confusing.

Int. J. LCA 4 (1) 2 – 3 (1999)

where M_i^n represents the amount of substance i that is released to compartment n, F_i^{nm} represents the fate factor that accounts for transport of substance i from compartment n to compartment m and for degradation within compartment n, I_i^{mj} represents the intake factor that accounts for the intake of substance i from compartment m by target j, and E_i^j represents the effect factor that accounts for the sensitivity of target j for the intake of substance i. The target dimension of Potting & Hauschild is thus replaced by an intake dimension, as its pure and independent core.

The independence of the four dimensions distinguished is clearly illustrated by the fact that it is not possible to write any of them as a superscript of one of the other dimensions. Fate, for instance, is not determined by effect, so the notation F^E makes no sense.

Let us now move to another aspect: temperature. It is clear that ambient temperature is an important factor in determining fate and possibly intake and effect, and that it therefore needs to be taken into account in characterization. But this does not mean that temperature is another independent dimension. If this were so, we would have to introduce a temperature factor T somewhere in the cascade of E, I, F and M. But, following the conclusion of the previous section, it would in that case be excluded to have a temperature dependency of any of those other dimensions. Temperature does not directly influence the category score S but only exerts its influence through the underlying dimensions, via independent mechanisms that cannot be summarized into one overall temperature factor T. Thus temperature, although obviously important in characterization, cannot be considered as an independent separate dimension. Instead, it is a modifier which influences the genuine dimensions fate and perhaps intake and effect. We could symbolize this by adding T as a parameter in parenthesis, like x in $f(x)$:

$$S_i^{nmj} = E_i^j(T) \times I_i^{mj}(T) \times F_i^{nm}(T) \times M_i^n \qquad (2)$$

In setting up this construction we have chosen to indicate some dependencies – such as substance and compartments – with sub- and superscripts, and others – such as temperature – as parameters in parenthesis. This gives rise to the natural question: what makes temperature T a parameter and what makes substance i a subscript? After all, we could also have written the fate factor as $F(i, n, m, T)$. The reason is more a practical than a fundamental one. In characterization, we aim at an aggregation of substances i, release compartments n and final compartments m. And we end up with category scores S specified per target system or category indicator j. In valuation, we may proceed towards a further aggregation of these targets. But we do not aggregate over temperature T, neither do we specify category scores S per temperature. So, our aim is to come up with something like

$$S^j = \sum_n \sum_m \sum_i E_i^j(T) \times I_i^{mj}(T) \times F_i^{nm}(T) \times M_i^n \qquad (3)$$

where the temperature-dependency is explicitly indicated.

Another example of a modifier/descriptor is background concentration. Like temperature, this type of information does not introduce a new dimension, but possesses the ability to modify some of the dimensions, in particular fate and effect. For the effect, it suffices to refer to the non-linear appearance of a typical dose-response curve, in which the incremental effect of a unit dose depends on the prevailing dose level. The eco-scarcity approach to impact assessment (Ahbe, 1990) is an example of an LCA-procedure that contains an effect factor that explicitly depends on the background level. In many proposals for impact assessment in LCA, on the other hand, it is typically excluded. Also for the fate factor, the background dependence is generally left out. This shortcoming may be problematic in certain situations: the fate of phosphate in a saturated soil, for instance, is quite different from that in a poor soil. We should also emphasize that fate and effect factor of a substance may depend on the background concentration of another substance. The effect of phosphate depends on the background concentration of nitrate, and the fate of aluminium in soil is partly determined by the background level of acidifying substances. How would this type of background dependency be incorporated? We propose to add the set of background concentrations $\{C\}$ that may influence the effect and fate factors as parameters in parenthesis:

$$S_i^{nmj} = E_i^j(\{C\}) \times I_i^{mj} \times F_i^{nm}(\{C\}) \times M_i^n \qquad (4)$$

We conclude that the modifier "background" of Udo de Haes can be described as a single parameter, while his modifier "spatial information" may be split up in a number of spatially varying parameters, such as temperature and background concentration, but also sensitivity, all of which appear as "descriptors" in the article of Potting & Hauschild. The separate dimension for "site" proposed by Wenzel et al. (1997) can be reinterpreted as a number of modifiers, since the independent dimensions of fate, intake and effect may all vary with local conditions. The form of the final characterization formula can thus be specified as

$$\begin{aligned} S_i^{nmj} = {} & E_i^j(T, \{C\}, NEC, \ldots) \times \\ & I_i^{mj}(T, \text{ respiratory volume, population density}, \ldots) \times \\ & F_i^{nm}(T, \{C\}, p\text{H}, \ldots) \times M_i^n \end{aligned} \qquad (5)$$

where the ellipsis […] indicate that there may be more types of modifiers.

The introduction of spatially differentiated modifiers necessarily requires the redefinition of the set of compartments into a larger number of more spatially refined compartments. This is, however, beyond the scope of this letter, and will be dealt with separately (Wegener Sleeswijk, in prep.).

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